

Business Case Analysis of the Towed Glider Air Launched System (TGALS)

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The Aerospace Corporation developed an integrated Business Case Analysis (BCA) model on behalf of the NASA Armstrong Flight Research Center (AFRC). This model evaluated the potential profitability of the Towed Glider Air Launched System (TGALS) concept, under development at AFRC, identifying potential technical, programmatic, and business decisions that could improve its business viability. The model addressed system performance metrics; development, production and operation cost estimates; market size and product/service positioning; pricing alternatives; and market share. Projected annual expenses were subtracted from projected annual revenues to calculate cash flow, return on investment (ROI), and net present value (NPV). This comprehensive model included parametric cost predictions for this system's development, production and operation, as well as adjustments for organizational complexity associated with integrating TGALS flight and ground components.

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Nomenclature

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|--------------------|---|
| <i>A-SOA</i> | = Advanced State-of-the-Art |
| <i>AFRC</i> | = Armstrong Flight Research Center |
| <i>BCA</i> | = Business Case Analysis |
| <i>CAD/CAM/CAE</i> | = Computer Aided Design, Manufacturing, and Engineering |
| <i>ICAM</i> | = Industrial Capability Assessment Model |
| <i>IM&P</i> | = Improvements in Methods and Processes |
| <i>IRR</i> | = Internal Rate of Return |
| <i>LEO</i> | = Low Earth Orbit |
| <i>LV</i> | = Launch Vehicle |
| <i>NASA</i> | = National Aeronautics and Space Administration |
| <i>NPV</i> | = Net Present Value |
| <i>PBP</i> | = Payback Period |
| <i>PIR</i> | = Performance Improvement Rate |
| <i>ROI</i> | = Return on Investment |
| <i>SME</i> | = Subject Matter Expert |
| <i>SOA</i> | = State-of-the-Art |
| <i>TGALS</i> | = Towed Glider Air Launched System |
| <i>TRL</i> | = Technology Readiness Level |
| <i>WBS</i> | = Work Breakdown Structure |

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he integrated TGALS Business Case Analysis (BCA) model identifies technical, programmatic and business factors that influence the commercial feasibility of the TGALS concept. The model includes parametric cost estimates for developing, integrating, testing, and producing key flight system and ground system components and associated equipment, as well as operational and maintenance costs of these components over the system's life. Cost projections were developed for different launch rates and maximum payload sizes (up to 600 kg). These estimates include both demonstration and operational vehicles. Business feasibility is assessed in terms of cash flows, Return on Investment (ROI), payback period, and Net Present Value (NPV), using both a traditional acquisition scheme as well as a funding mechanism proposed by NASA-AFRC. To improve objectivity, program independent historical data and analyses were used whenever possible to benchmark calculated financial metrics and program estimated values and to provide sensitivity analysis for the differences identified.

I. Introduction

II. Analytic Framework

A. TGALS System Components

The TGALS system includes a modified tow aircraft, glider, glider rocket motor, launch vehicle (LV), and ground infrastructure. The glider with under-carried LV is shown in Figure 1. This concept has many advantages:

- High Performance
 - Lifting of significantly larger geometric payloads to altitude vs. modifying a same-size business jet or commercial transport aircraft to carry the launch vehicle externally
 - Ability to release the LV at an elevated flight path angle and high altitude coincident with the optimal trajectory for the LV
 - Up to 70% increase in payload weight to orbit (vs. ground launch), 30% increase due to releasing the LV at an elevated flight path angle by the glider performing a “pull-up” maneuver prior to LV release (Figure 2).
- Agility
 - Low overhead flight operations allows for rapid turn-around to launch satellites quickly
 - No dependence on critical ground-based launch facilities/assets
- Safety & Mission Assurance
 - Unmanned glider eliminates human safety concerns for carrying LV
 - Restartable sustainer motor extends glide home distance following launch or abort
 - Glider capable of landing with LV attached in event of mission abort

- Flexibility
 - Glider plug-and-play center wing allows multiple simultaneous LV build-ups
 - Inexpensive gliders can be staged at nearly any airfield, increasing launch opportunities
 - Tow plane can be a slightly modified existing aircraft that simply adds towed launch to duties
 - Glider concept is scalable from very small to larger LVs

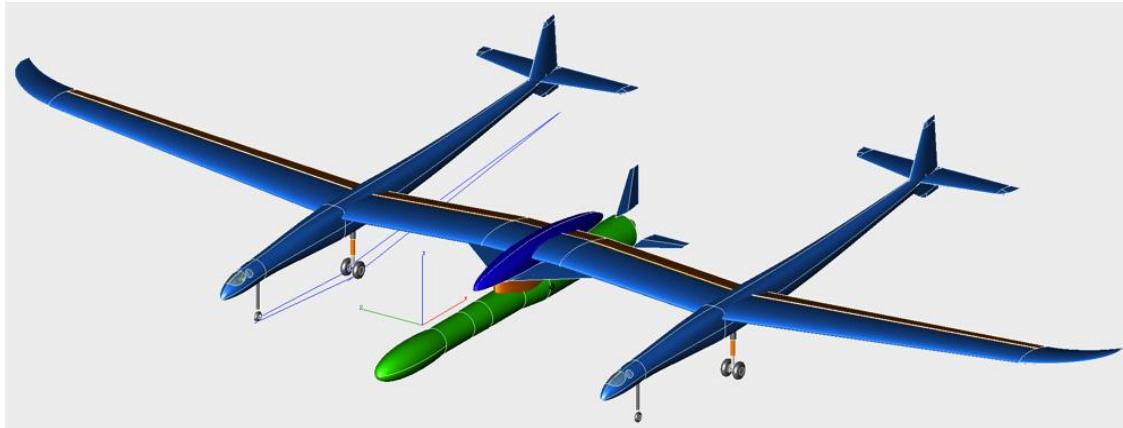


Figure 1. TGALS Glider and Launch Vehicle

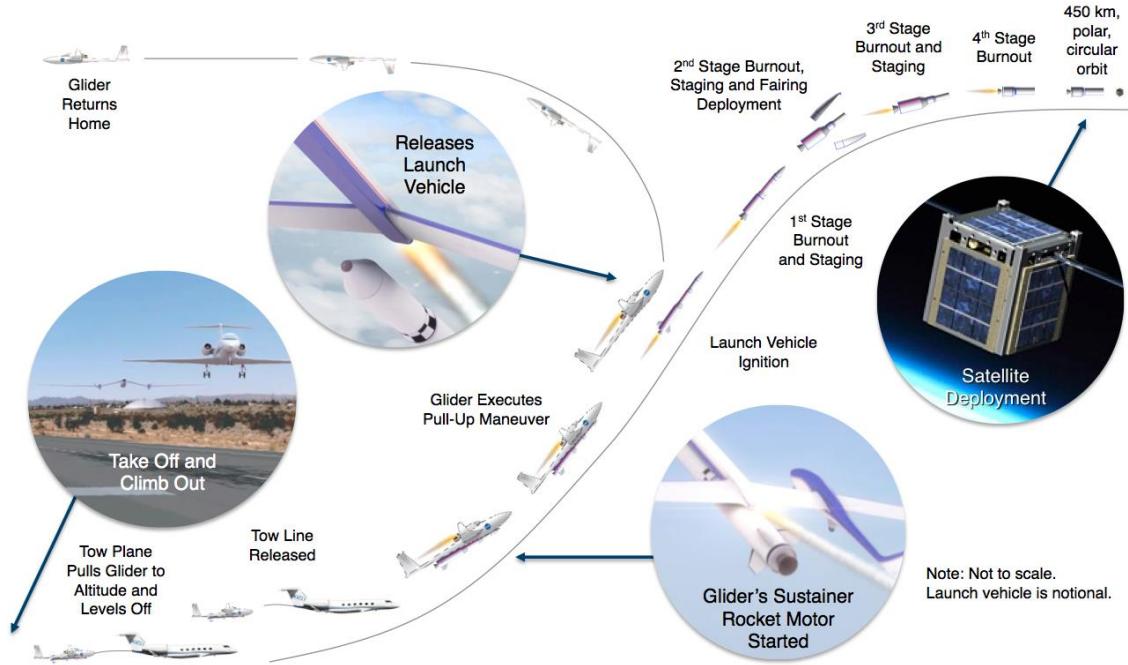


Figure 2. Pull-up Maneuver

B. BCA Architecture

An overview of the Aerospace Corporation developed solution for the TGALS BCA is shown in Figure 3. The solution consists of linking several models into a decision framework. Subject Matter Expert (SME) inputs were used

to customize Aerospace's Industrial Capability Assessment Model (ICAM), which is a technology-based cost model (upper left of Figure 3).

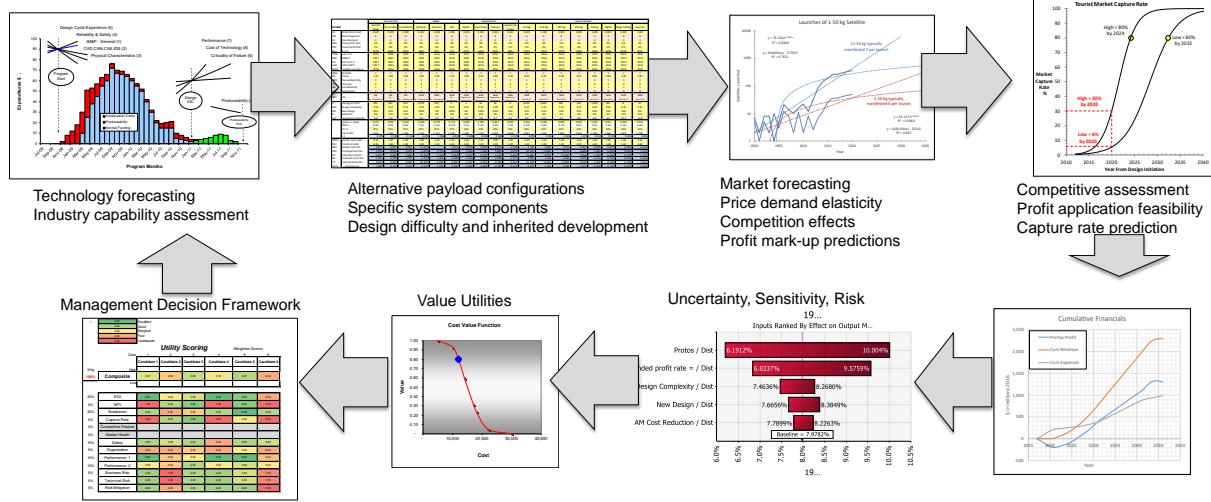


Figure 3. BCA Modeling Architecture

For the model, the TGALS performance capability is assessed against customer decision factors and LV market forecasts. Market capture rate forecasts are based upon market demand, price, competition, and price elasticity (upper right of Figure 3). Time phased expense and revenue streams are used to calculate financial metrics such as ROI and NPV. Monte Carlo simulations are used to quantify risk (effects of input uncertainty on the modeling results). Optional value functions are used to adjust weighting factors for TGALS system characteristics (i.e., resilience, price, launch convenience). In the lower left of Figure 3, several candidate configurations are scored for desirability. A rollup of metrics gives a composite score for each system candidate in the management decision framework. Business case desirability is improved through optimizing the model's output through consecutive iterations.

C. Capturing Advantages of the TGALS Concept

The unique and technologically diverse characteristics of TGALS cover a wide range of legacy systems that take advantage of the reusability and efficient flight physics of gliders (Figure 4). An existing aircraft is modified for towing, becoming a human-rated reusable first stage. The glider and the sustainer rocket motor is a new, non-human-rated and reusable second stage. The launch vehicle is ignited in a steep climb above 40,000 feet altitude in lieu of a ground launch. Because the takeoff is from an airport without a launch pad, the ground infrastructure required is minimal. The tow aircraft is a modified business jet or commercial transport for larger payloads, either one with minimal modifications using mature technologies. Components of the modeling system chosen by Aerospace are designed to capture the advantages of TGALS concepts, viz., (1) reusability, (2) technological maturity, (3) existing designs with minimal modifications, and (4) human and non-human rating.

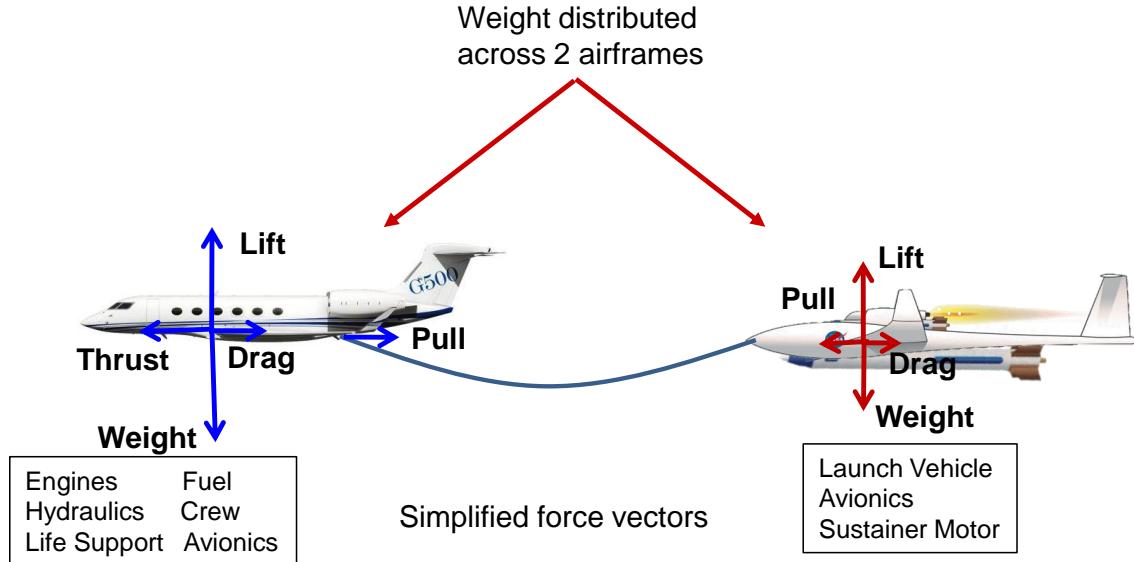


Figure 4. TGALS Force Vectors

III. Major Modeling Components

A. Industrial Capability Assessment Model (ICAM)

The ICAM¹ hardware cost prediction model is an Aerospace-built parametric system based upon the movement of technology over time correlated with concomitant costs. The primary drivers are described below:

1. CAD/CAM/CAE – Based on the year of the version of Computer Aided Design (CAD). Design costs are reduced as later versions of CAD are utilized. Older legacy systems might initially result in reduced design costs. However, these systems are more expensive to modify and maintain (Figure 5).
2. IM&P – Improvements in Methods and Processes – Based on the year the equipment is developed. It represents the general processes and methods of inventory control, machining, material process sophistication and assembly, and test procedures (Figure 5).
3. Producibility – Describes the amount of time dedicated to mature the manufacturability of a product, reducing complexity, mass, and the number of parts and therefore cost (Figure 5).
4. Design Cycle Experience – The year indicating the experience level of program management and systems engineers. This is the number of programs they have experienced from beginning to end (i.e., program cycle experience). Present-day engineers tend to have experienced fewer programs than engineers working in the 1960's and 1970's. Having fewer program experiences results in needing more hours to finish tasks, less insight for decision making, and potentially increased costs (Figure 5).
5. Performance Improvement Rate (PIR) – The rate of technology increase of the equipment on an annual compounding basis. Chosen from a library of hundreds of ‘Moore’s Laws’ (Figure 5).
6. Cost of Technology – The cost of increasing technology over time expressed as an annual compounding percentage. All things equal, the cost of technology increases but at a slower pace than the PIR thus yielding greater capability per dollar than older technologies (Figure 5).
7. Design Complexity – A table value that describes the difficulty of the engineering task ranging from simple engineering support to difficult advancement of the state-of-the-art (SOA) above the normal technology path.
8. New Design – The amount of a normally complete engineering task that needs to be accomplished expressed as a percentage.
9. Internal and External Integration – These values are used to reflect the difficulty of integrating elements of the equipment.
10. Prototypes – The amount of development and test hardware including simulators, engineering developmental models, prototypes, and qualification units.
11. Planned Build Quantity – The number of production units planned to be built. As planned build increases so does development cost due to producibility and quality concerns. Planned build affects the production T-1

value and the cost quantity improvement curve. For example, very high planned build rates simplify the design, set the tooling rate, and increase automation, therefore flattening the production rate curve.

12. Production Quantity – The current build quantity needed.

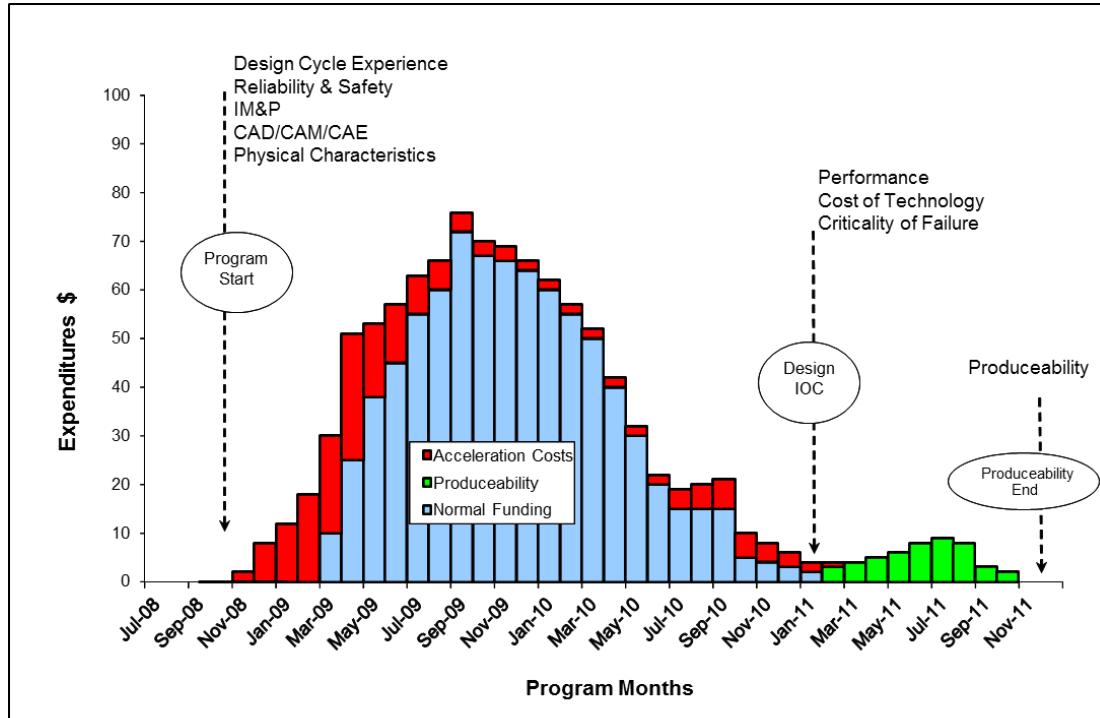


Figure 5. Multidimensional Technology Applied to Cost

The above variables are considered together and are highly interdependent. For example, a low new-design value for an older legacy system is not consistent with a current-year CAD/CAM/CAE value. These interrelated concepts are important in characterizing real-world issues present in all programs. Accurate characterization is necessary to develop an accurate BCA. For each flight system equipment item, a historical analogy is selected, and the model changes historical costs to the TGALS system conditions serially by dimension. For example, the glider was compared to the Lockheed U-2. The U-2 historical costs, physical description, and technological conditions were calibrated into ICAM. Subsequently ICAM changed the U-2 into a TGALS glider one step at a time through all technology and physical dimensions. These steps included demilitarization as well as modernization.

B. Organization Complexity

One disadvantage of the TGALS concept is the relatively complex organizational structure required due to the diversity of flight system component types. The tow aircraft (an existing business jet or aerial tanker), glider, sustainer motor, and launch vehicle are designed and built by different companies, necessitating a sophisticated management, procurement, and logistics structure within the TGALS organization. The Aerospace cost modeling system increased TGALS integration and management costs to capture the more complex business and engineering environment as compared to a “flat” organization that builds and operates standard launch vehicles.

C. Market Size Forecast

The microsatellite market forecast by SpaceWorks Enterprises, Inc. (SEI) in 2016² predicts an escalating demand for launch services for the smaller satellites that is driven by the commercial sector’s interest. In order to forecast market launch rates, annual smallsat launch rates were analyzed and annual growth rates measured (Figure 6). To account for multiple manifesting per launch, projected annual launch rates by payload capacity were projected. The TGALS study displayed the scalability of the launch concept for satellites up to 550kg.

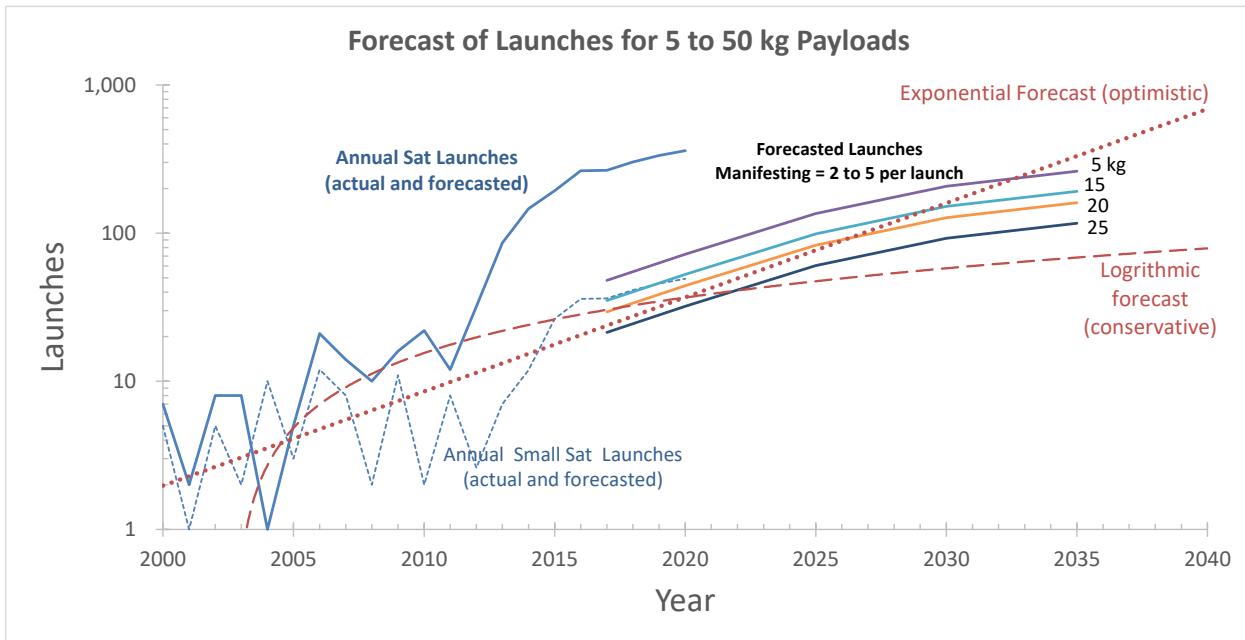


Figure 6. Market Forecast

The launch forecast has variability resulting from a significant number of proposed new smallsat LV entrants, each with different manifesting strategies and payload capacities. Not all of these will be launched. However it should be noted that the forecast used is very conservative in the out years as compared to the historical trends. Even the early years (2017-2025) are conservative as they do not account for the payload backlogs resulting from the launch failure down times that occurred in 2014 and 2015.

IV. Evaluation Process

A. Program Assumptions

Technical and physical equipment, ground infrastructure, and task descriptors are input into the modeling system to document the process and approach. This includes task descriptors and technological metrics to components as small as the tow cable reel mechanism and the cable within the tow aircraft. These inputs are too numerous to list in this paper. Some of the main cost and market drivers are listed below:

- Market assessments and financial returns include operations to 2040
- Profit margins charged are reflective of marketplace competitiveness
- New flight providers to Low Earth Orbit (LEO) = 11, survival rate for new providers = 70%
- Each flight vehicle design approach is assumed successful
- No disruption due to catastrophic failure is included
- Hosted payload market is minimal after 2017 due to increase in small LV providers
- Flight growth rate to 2030 = 19% compounded (The 2012-2015 smallsat growth rate was 27%).
- Tax Rate = 35%
- No insurance is included
- Various payload capacities
- Tow aircraft range from business jets to firefighting tankers
- Tow aircraft rented on demand or fully owned

B. Financial Metrics

Modeling of TGALS performance, physical characteristics, development costs, flight test costs, infrastructure costs, market size, market capture, resultant production quantities, operations costs, gross revenue, and profits are all necessary components for calculating financial evaluation metrics. Three commonly used financial metrics were used to evaluate TGALS as a viable business venture, i.e., ROI, NPV, and PBP:

- **Return on Investment (ROI)**

ROI is a financial investment metric used to gauge the efficiency of alternative investments in selecting the best investment. ROI is a measure of financial return on the investment cost. ROI is popular due to its simplicity of calculation and wide applicability. A weakness of ROI is that it does not consider the amount of time required to achieve the return.

$$\text{ROI} = (\text{Gain from Investment} - \text{Cost of Investment}) / (\text{Cost of Investment})$$

The ROI calculated for the TGALS program as envisioned is conservatively 8.3% based upon launch rates of 8 to 22 launches a year. The profit margin on the launches is based upon price reductions from competitive launch rates. The predicted ROI appears realistic because (1) conservative inputs were used in the analysis in areas where uncertainty exists and (2) a large number of elements in the WBS was input to assure completeness of the cost estimate.

- **Payback Period (PBP)**

PBP is often used to supplement ROI as it is simple to calculate and accounts for the time required after investment to recoup the investment. As such, PBP does not indicate profitability of a project, although it can be cautiously assumed on some projects that a rapid PBP is usually more profitable than a longer PBP. Time spreads of TGALS estimated costs and revenue indicate a reasonable PBP of 6 to 8 years. This PBP value is short for launch vehicles due to the large use of existing flight components and simple infrastructure composing the TGALS system.

C. ROI Variable Uncertainty

Palisade @RISK, a commercial Excel add-in package, was used to quantify the impact of input uncertainty on the model's output. Palisade uses the Monte Carlo method of statistical distributions to simulate the BCA model results when operated thousands of times within the ranges specified for selected input variables possessing substantial uncertainty. This method has been used extensively in the aerospace cost estimating community since 1965. This section will discuss the inputs, outputs, and sensitivity of this analysis.

- **Resulting Probability Distribution and Sensitivity**

Simulation of the TGALS program 5,000 times was performed with the six variables having substantial uncertainty varied within specified ranges, to create Figure 7. The six variables were LV recurring cost, profit margin, annual launch rate, glider maintenance cost, payload capacity utilization, and estimate reserves. Using conservative data interpretations and input ranges and a comprehensive WBS, the resulting ROI financial metric was the lowest, at -3%, when all variables were simultaneously pessimistic. This is not expected to occur. Similarly, all optimistic variables happening simultaneously yielded a ROI of 24%. A more useful statistic is an expected ROI range from 3% to 14%, which includes 90% of all expected input value combinations. The most realistic occurrences of the variables provides a mean ROI expected value of 8%. Considering that the input values and analysis are conservative, the 8% ROI is favorable.

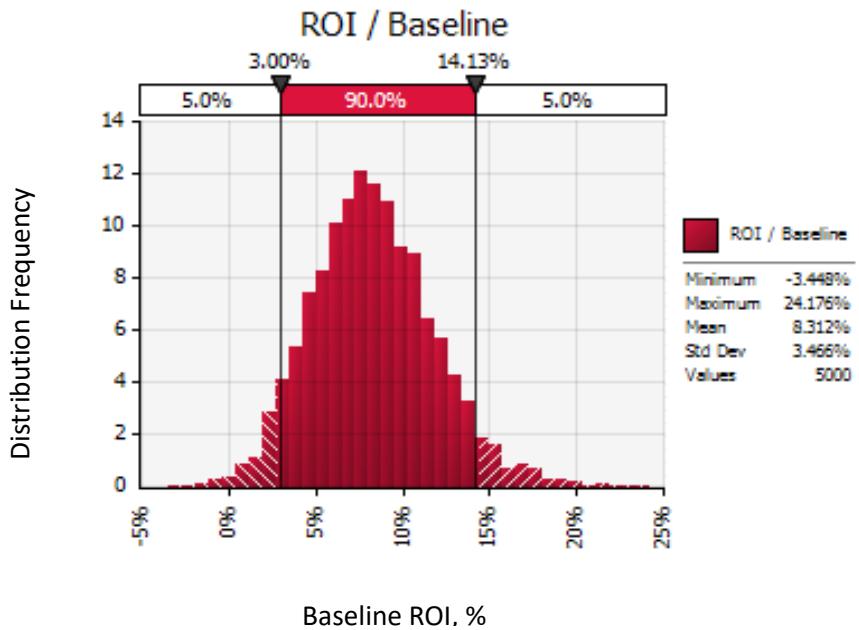


Figure 7. ROI Probability Distribution

Another way of observing the ROI output is by using the cumulative probability distribution shown in Figure 8. As an example, the reader can move horizontally to the right from 0.5, which represents 50%, to the 's' curve and then proceed down to 8%. This shows that there is a 50% probability of 8% ROI. Reading horizontally from 0.8 (80%) to the curve and down shows that 80% of all occurrences of ROI simulation are below 12%.

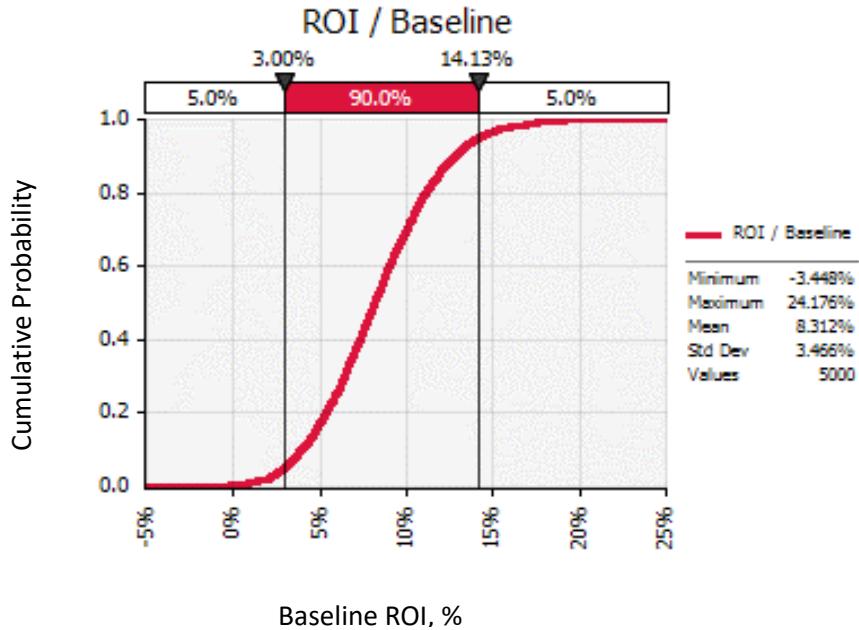


Figure 8. ROI Cumulative Probability

As shown in Figure 9, several input variables dramatically drive the ROI. The variables selected for drivers of uncertainty include LV recurring build cost, profit margin chargeable in a competitive market, annual launch rate, glider maintenance cost, amount of total payload capacity utilized by multiple manifests, and estimate reserves. Estimate reserves are extra costs applied to the cost estimate for unknowns. The variables are listed in Figure 9 in

order of importance driving uncertainty. In this case the recurring LV cost and the chargeable profit rate each play significant roles.

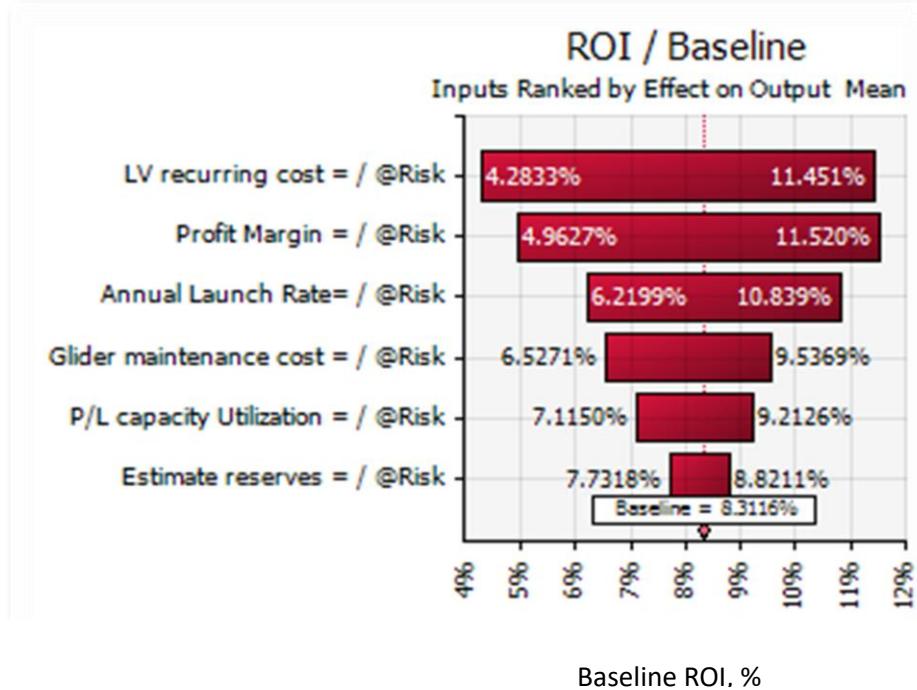


Figure 9. Inputs Driving ROI Uncertainty

V. Summary

A. Observations

Several notable observations were derived from the BCA analysis:

1. The effect of a long and expensive flight test program can be devastating to financial success metrics. A long flight test program will add expense and push the revenue stream further out, delaying cash flow. On the other hand reduced testing increases the chance of a catastrophic failure, which would drive cost up even faster and delay financial returns even higher should it happen. The effects of a catastrophic failure on the TGALS program have not been modeled. A human safety event in TGALS is unlikely as the pilots of the tow aircraft are operating mature commercial aircraft and are separated from new system components by the nature of the system architecture.
2. Small LV market predictions are difficult in the small satellite market as multiple manifesting is a large uncertainty factor. Also large numbers of small satellites will be launched on large LVs as dispensers improve. Due to multiple manifesting, a LV failure with large numbers of small satellites can vary the total market by as much as 30% in a single year. For example, the actual launch rate in 2015 was 30% less than the SpaceWorks average annual launch forecast for 2015². The overprediction by SpaceWorks was caused by the Falcon 9 failure in June 2015² and the Super Strypi failure in November of 2015². The Super Strypi launch failure alone was responsible for the loss of 51 small satellites along with the primary payload².
3. Multiple configurations of flight systems with a full range of payload sizes were studied. A problem was encountered with predicting capture rates when the larger payload TGALS configuration competed with the smaller payload configuration.
4. When focusing on total cost, a design change of \$25 million does not significantly change total investment cost in the \$500 to \$1B program class. Yet it has a much greater impact on investment statistics such as ROI. The \$25M

may be an increase of 5% to 10% of development cost, but from the profitability standpoint it can push the break-even point and profits out as much as a year.

B. Conclusions

Based upon extensive modeling and cost trade studies, a successful solution to the TGALS business case was developed. This is composed of mostly low risk components compared to typical new launcher development programs and is sufficiently robust in its components that alternatives exist that greatly enhance the business case viability. One major example of this is the rental of tow aircraft made possible by the minimum number of aircraft modifications that are necessary. Importantly, because the BCA model was comprehensive and detailed in description of design characteristics, programmatic, and market assumptions, all decisions and alternatives could be explored with the focus on financial returns for a commercial investor. A summary of the TGALS low-cost characteristics follows:

- No new infrastructure costs
- No dependence on critical ground based launch facilities
- Relatively inexpensive to build a glider vs. modifying a conventional airplane
- Glider has low maintenance costs compared to a conventional airplane
- Existing business jets and tanker aircraft can be used as tow vehicles with minimal modifications

Although the trade space explored in the TGALS BCA was too large to discuss here in entirety, Figure 10 provides an example of results from one trade study under defined successful conditions. Based upon the number of launches ranging from 5 to 25, this TGALS payload capacity became highly competitive in price with a 30-60% margin above 10 launches per year. The ROI gained attractiveness at 10 launches per year with a 60% margin. These margins appear feasible as a function of the physics advantage of the towed glider coupled with a robust and flexible concept composed of relatively low risk technologies.

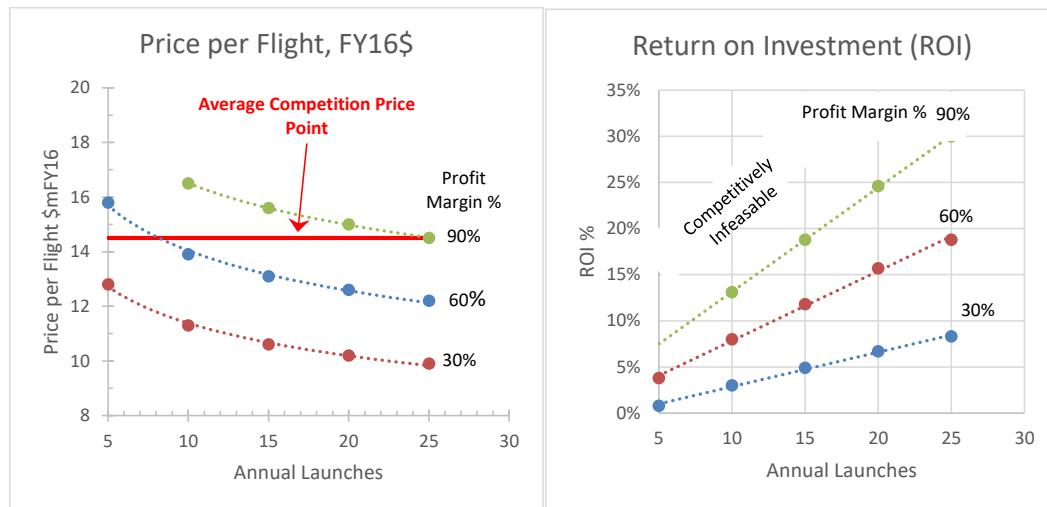


Figure 10. Price per Flight and ROI versus Annual Launches

A healthy and robust launch rate is necessary for a successful business case for launch vehicles. The baseline analysis of 60% profit margin yields an 8% ROI on 12 launches. But as the right side of Figure 10 shows, a capture rate of 20 launches a year (+67%) doubles the ROI to 16%. A launch capture rate of 20 per year, although historic, is not unreasonable for a system with mostly reusable components such as TGALS. This is true especially considering the conservative nature of the BCA performed. A summary of the conservative BCA elements follows:

1. The WBS was very detailed in all categories from development and production costs, operations costs and infrastructure.

2. The model accounts for changing technology, advanced design processes, and industry skill levels.
3. The model inputs passed a grueling ‘vetting’ by Aerospace Commercial Launch and Systems Engineering cost experts midyear 2017 to assure a lack of ‘wishing and hoping’ so commonly characteristic in BCAs.
4. Estimate reserves were added to account for any ‘I forgots’ or ‘unknown unknowns’ in addition to the uncertainty simulation.
5. The launch forecasts do not account for the increased ease of using new launch adapters or future smallsat launch surges due to delays in manifesting caused by large LVs.
6. Analysis included changing market conditions and improvements in the positions of competitors as opposed to the market remaining constant in manifesting, efficiency, and competitive pricing strategies.

In summary, the model indicates that TGALS variants present viable positive business cases.

Acknowledgments

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